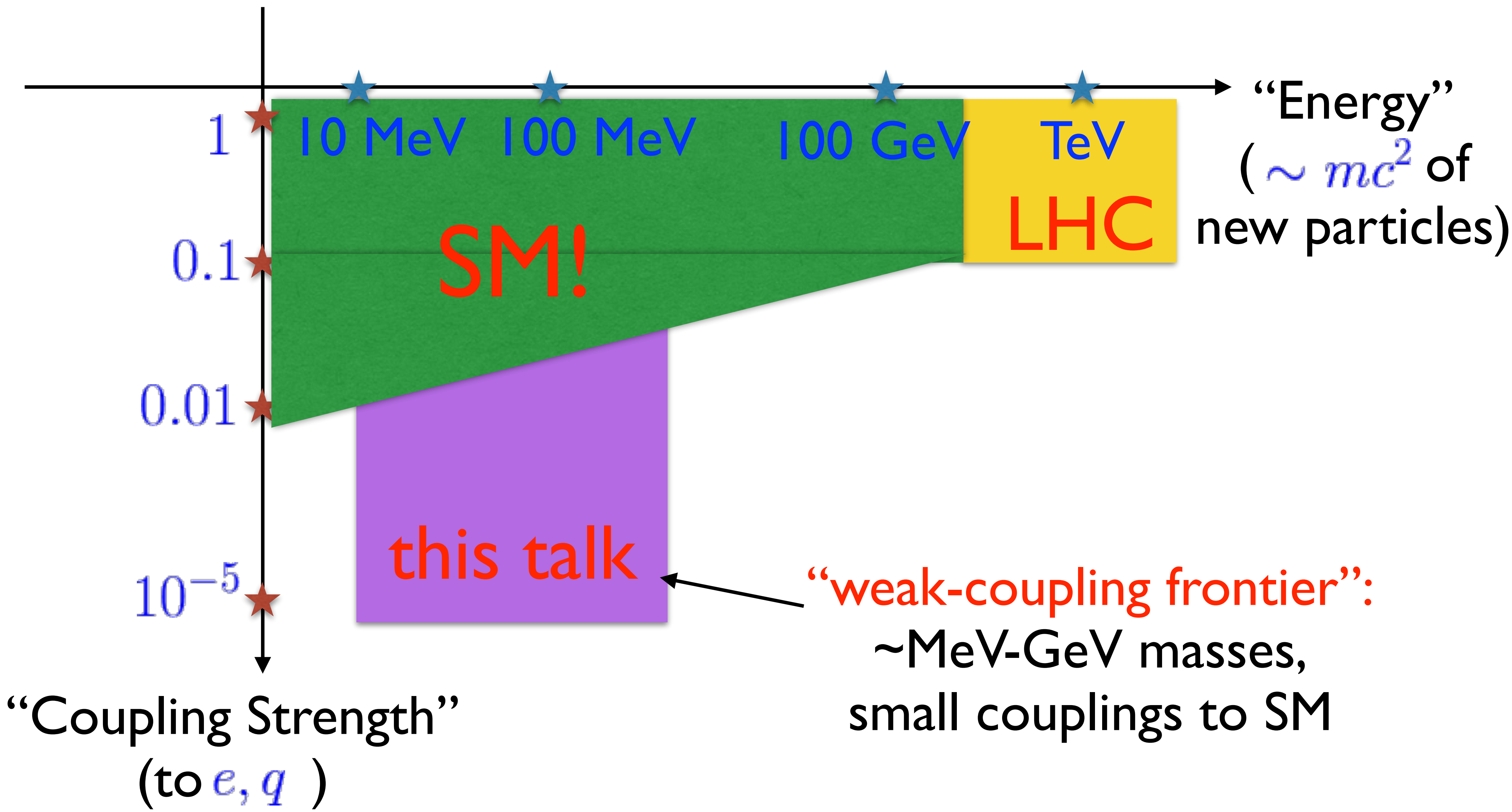
Particle Physics Experiments with Cornell's FFAG ERL

Maxim Perelstein, Cornell University

ERL-2015 Workshop, Stony Brook, June 10, 2015

Frontiers of Particle Physics

- #1 Priority in particle physics is to test the Standard Model, and hopefully find new physics beyond the SM



FFAG ERL for Particle Physics

- High current enables higher precision measurements, sensitivity to smaller cross sections for rare processes
- We recently began exploring opportunities for particle physics experiments @ FFAG ERL
- Workshop on “Physics with Intense Electron Beams” at Cornell next week, June 17-19

	Unpolarized	Polarized	Unit
Energy(1)	300	300	MeV
Power	12	3	MW
Current	40	10	mA
Bunch frequency	1300	1300	MHz
Normalized Emittance$_{x, y}$	0.3	0.3	mm-mrad
Bunch duration	2	2	ps
Energy spread	0.02	0.02	%
Polarization	0	90	%

INTENSE ELECTRON BEAMS WORKSHOP
CORNELL UNIVERSITY, JUNE 17-19, 2015

CORNELL LABORATORY FOR ACCELERATOR-BASED SCIENCES AND EDUCATION — CLASSE

Registration will close on May 31, 2015.

With the advent of high power photoinjectors and high performance superconducting RF acceleration, there is the potential for low energy electron beams with currents up to 10 times higher that those generally available today. This workshop will explore the physics opportunities that will be opened up by such beams, focusing on **parity violation**, the search for **dark matter, dark photons and axions**, and **electromagnetic nuclear physics**, as well as the accelerator, detector, target and polarimetry **technologies** that make them possible. Discussion will focus on electron beams with energies up to 500 MeV and electron current of up to 100 mA (unpolarized) and 10 mA (polarized) with energy recovery, with the goal of answering:

1. What is the potential reach of experiments using very intense low energy electron beams?
2. What technical challenges need to be overcome to reach those goals?

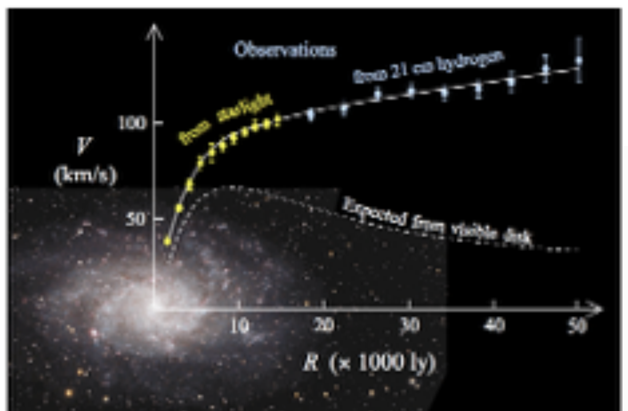
Quick Links

- IEB Workshop Home
- Program
- General Information
- Electron beams
- Registration
- Participants
- Accommodations
- Travel
- Visas

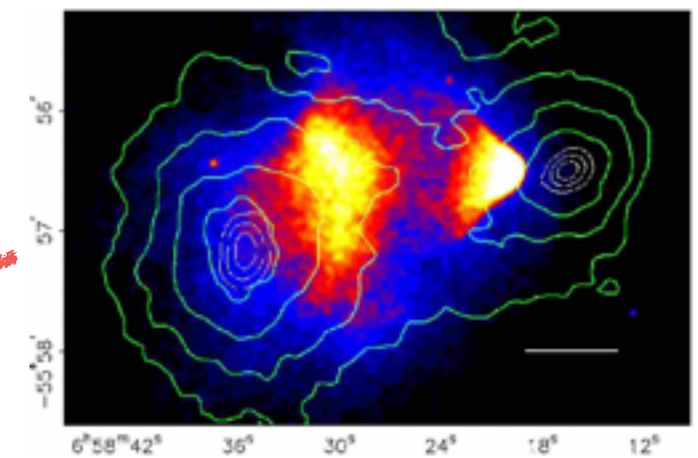
http://www.classe.cornell.edu/NewsAndEvents/IEBWorkshop/

Why Weak Couplings?

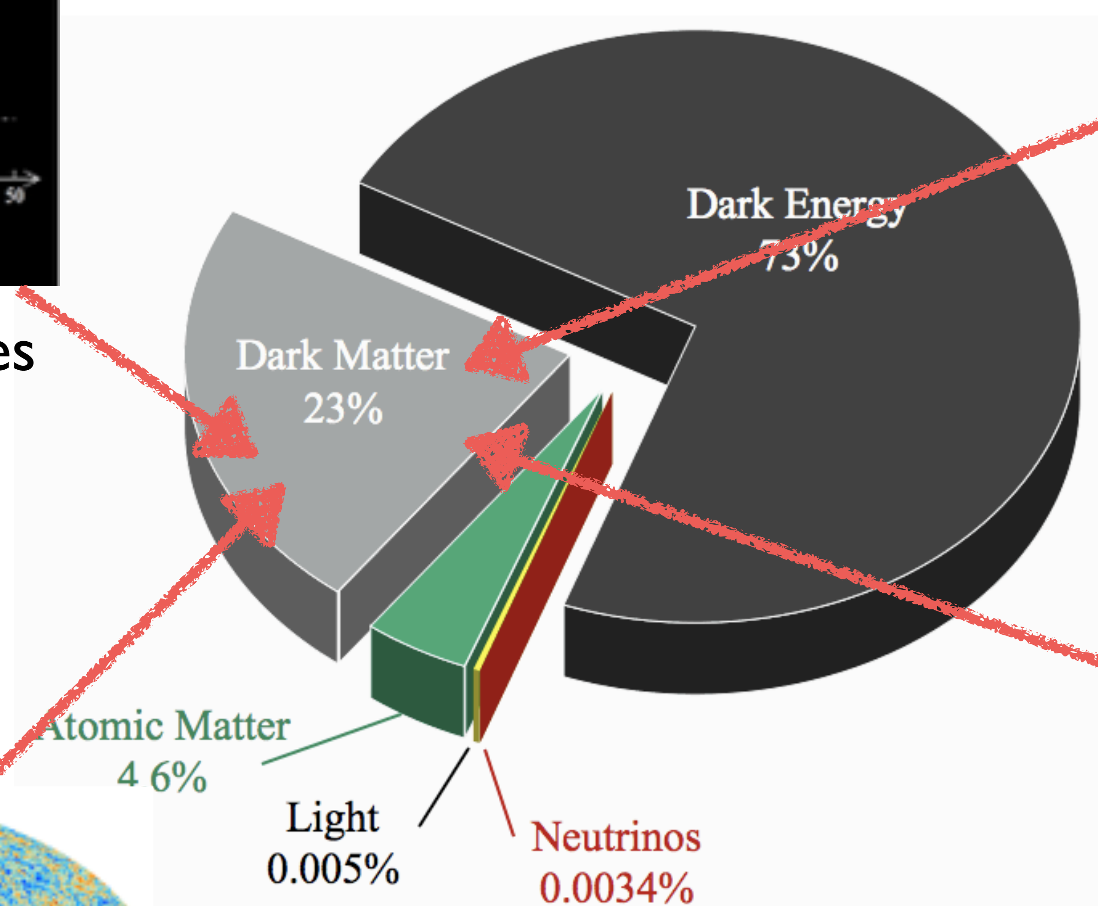
- Motivation for new weakly-coupled particles is provided by the existence of dark matter



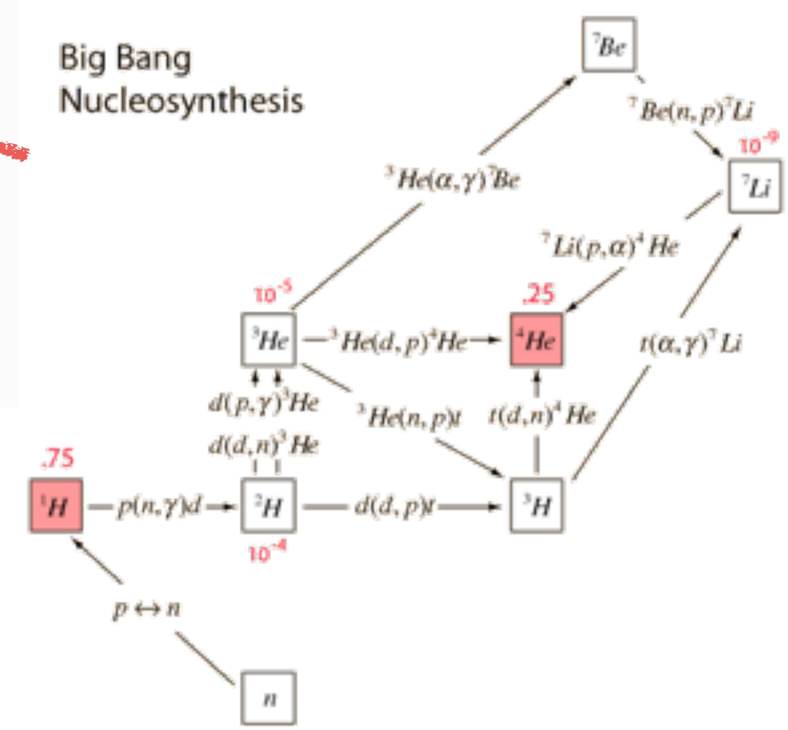
galaxy rotation curves

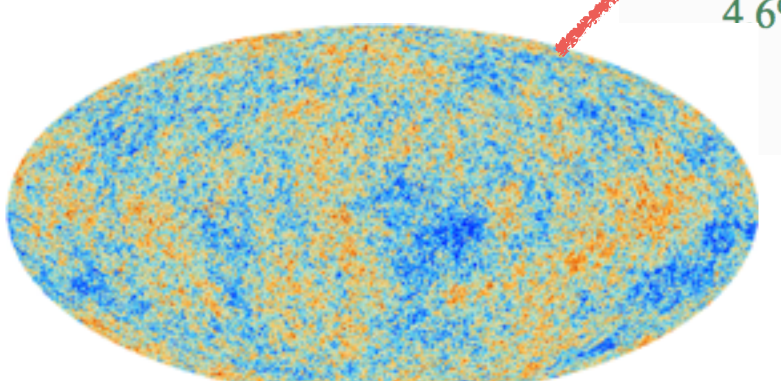


Bullet cluster



Big Bang
Nucleosynthesis

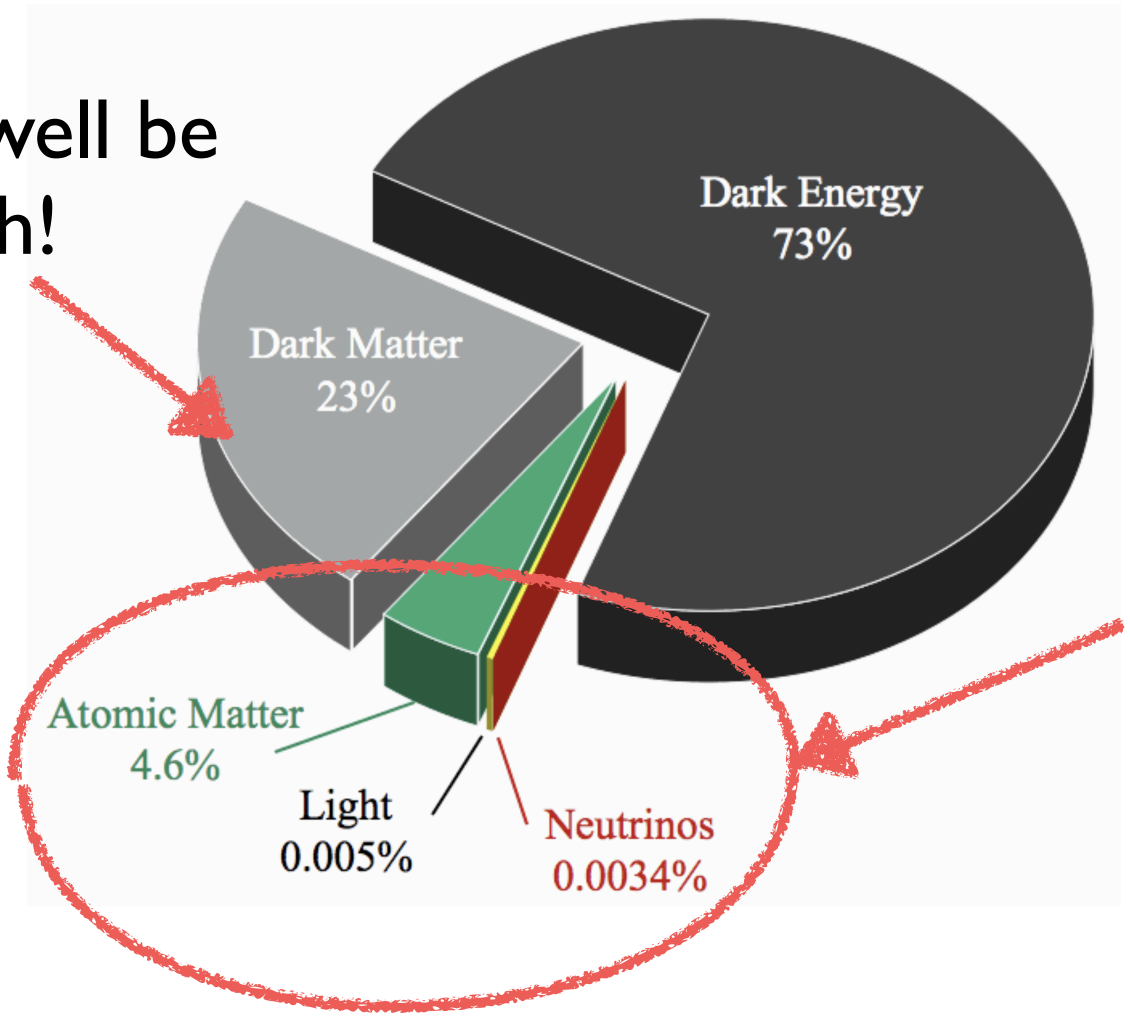




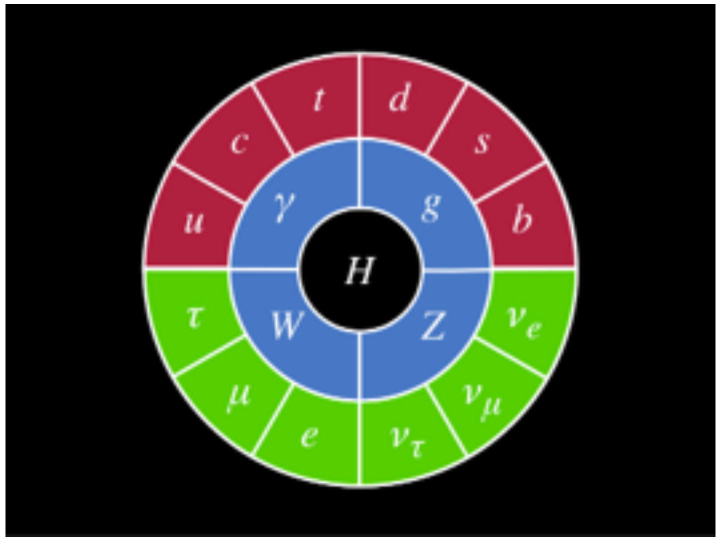
cosmic microwave background

Dark Matter & Dark Sectors

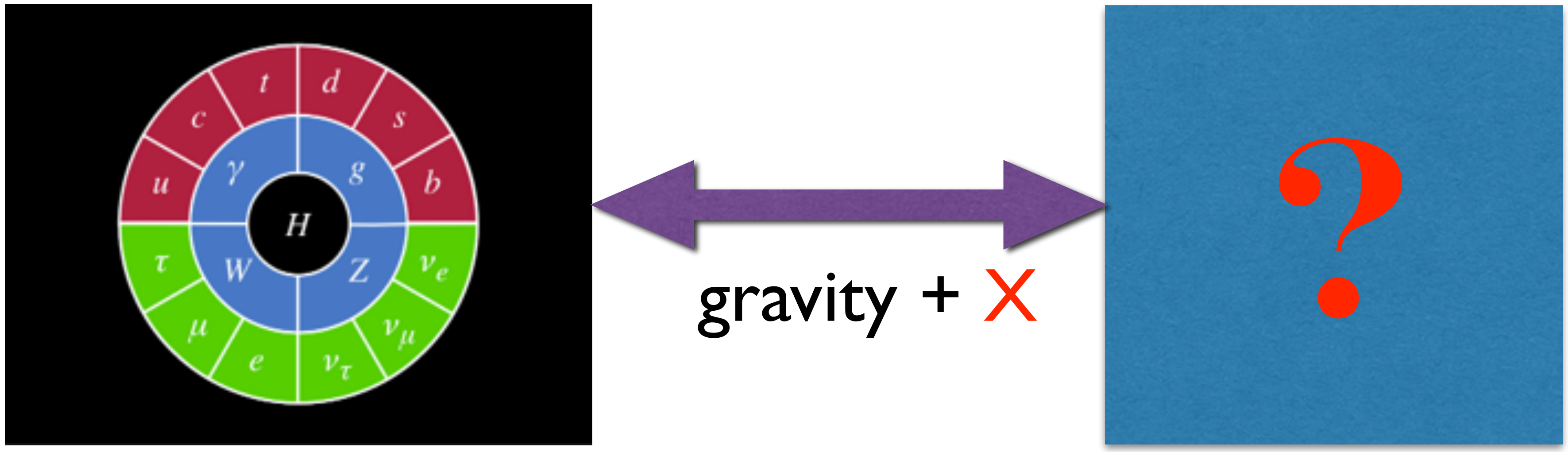
DM 23%: may well be equally rich!



SM 4%: rich structure, only a small subset of states are "abundant"



Dark Matter & Dark Photon

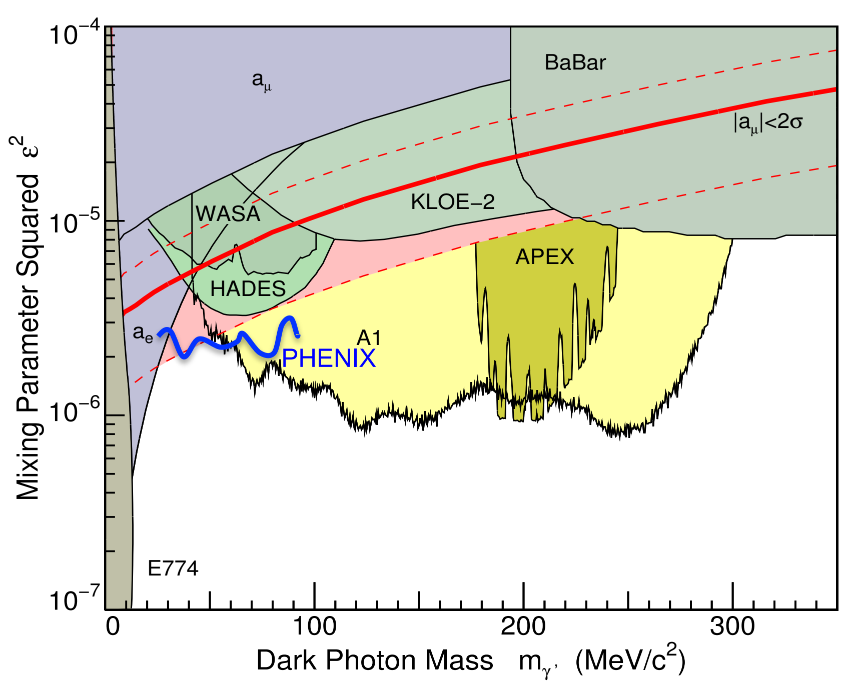


- “Dark” matter means interactions with the SM < EM strength ($\alpha = 1/137$)
- Natural to consider two sectors, with EM-strength interactions within each one, but only feeble “portal” interactions between them
- We know that Dark Sector gravitates, but is there any other portal?
- A generic possibility is Dark Photon: almost inevitable if the Dark Sector contains “dark electromagnetism”

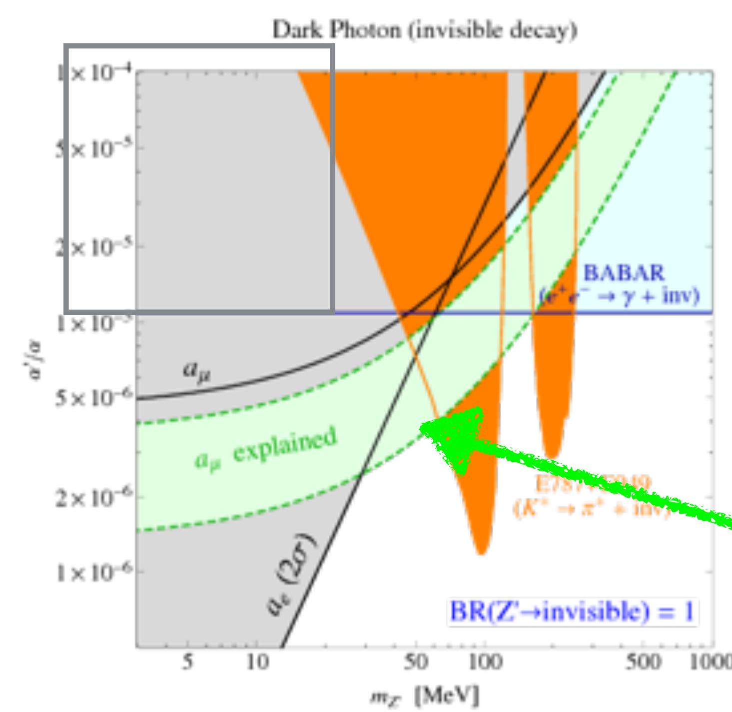
$$\Delta\mathcal{L} = \frac{\epsilon}{2} F^{Y,\mu\nu} F'_{\mu\nu}$$

Dark Photon Searches

- Mixing induces coupling of DP to SM quarks/leptons, $\propto \varepsilon\, e$
- Parameters: $M_{A'}$, ε
- DP may dominantly decay either to e+e-, or to dark sector states ("invisible")
- Loops of DP may contribute to muon g-2, potentially explain E821 anomaly (3.6σ deviation from the SM)



Visible: $A' \to e^+e^-$



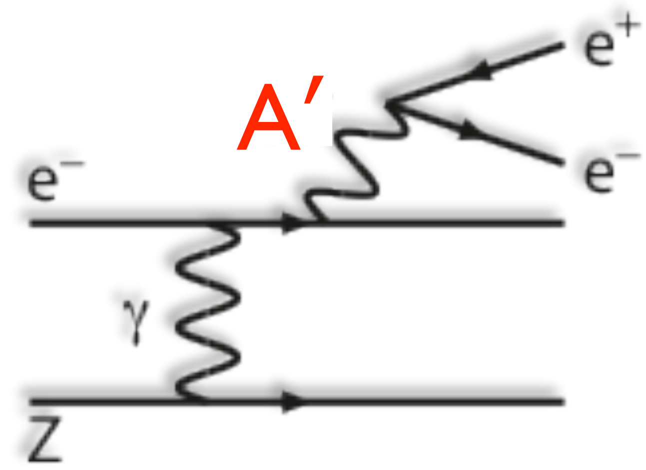
Invisible: $A' \to \chi\chi$

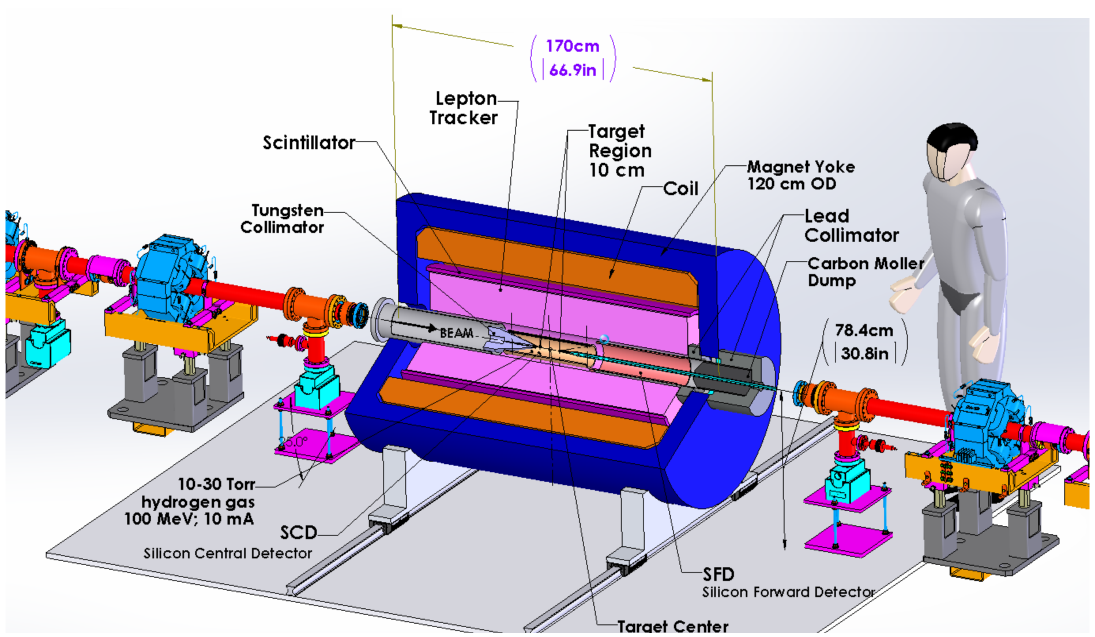
Upshot:
$\varepsilon > 10^{-3}$
is ruled out

Part of a region explaining g-2 still alive!

DarkLight Experiment

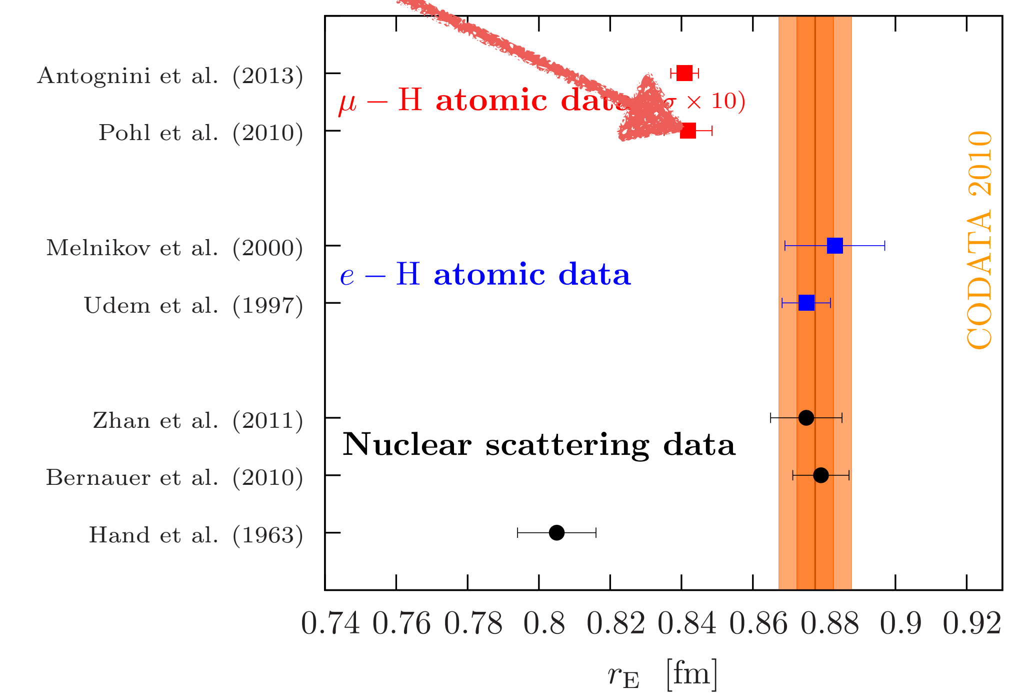
- DarkLight Phase I now under construction (run at JLab FEL in 2015 or 16?)
- Feasibility study for FFAG ERL is in progress by Cornell+MIT group [R. Milner et al]
- High current allows for improved reach in ε
- High current → compact target → vertex reconstruction, especially useful for invisible DP search
- Internal target fulfilling DarkLight requirements seems compatible with FFAG ERL design [C. Mayes]

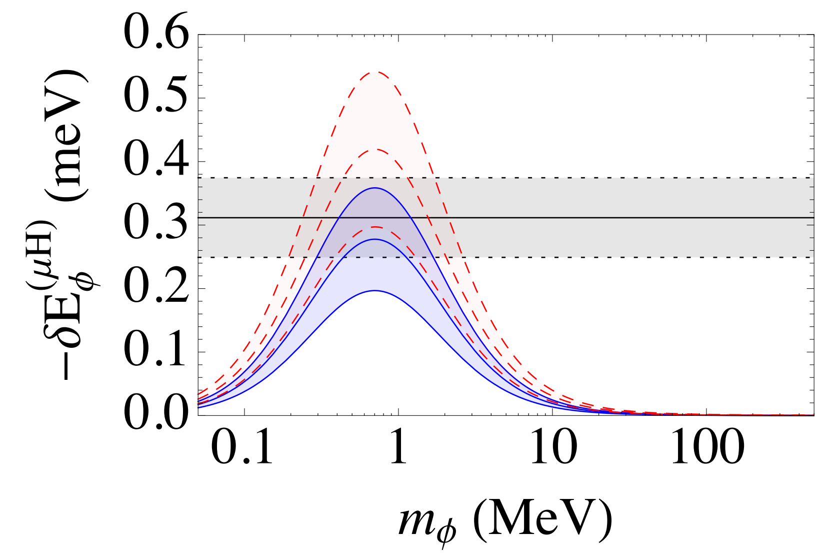




Proton Charge Radius

"8-sigma" discrepancy!





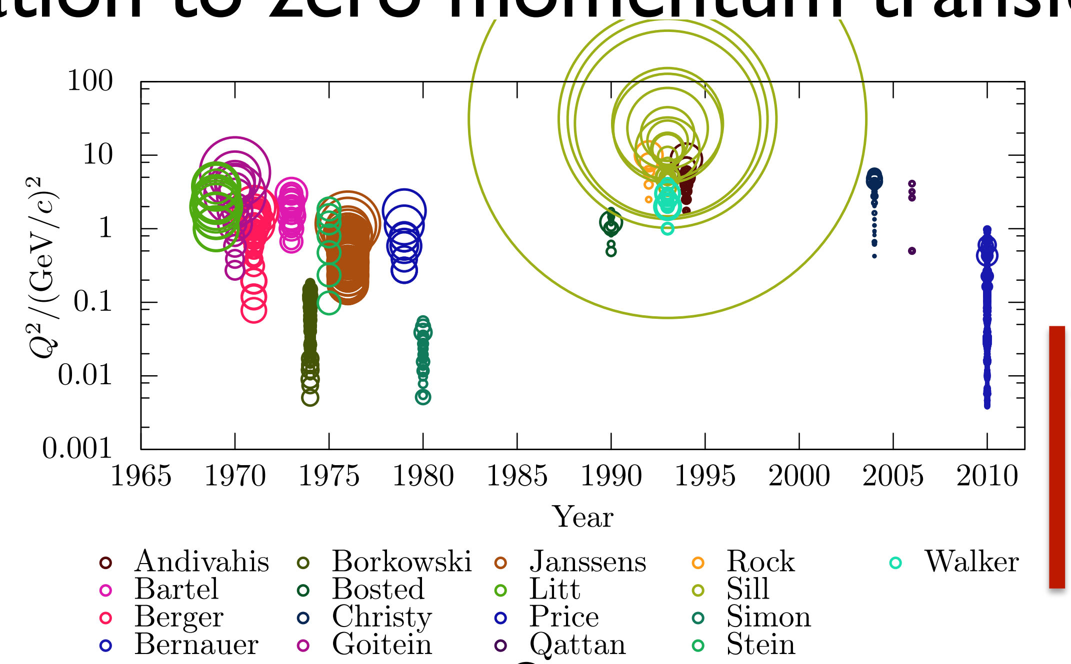
$g \sim 10^{-4}$

Scalar coupled to μ but not e can explain both Rp and g-2

[Tucker-Smith, Yavin,'10]

Value extracted from elastic ep scattering subject to errors from extrapolation to zero momentum transfer:

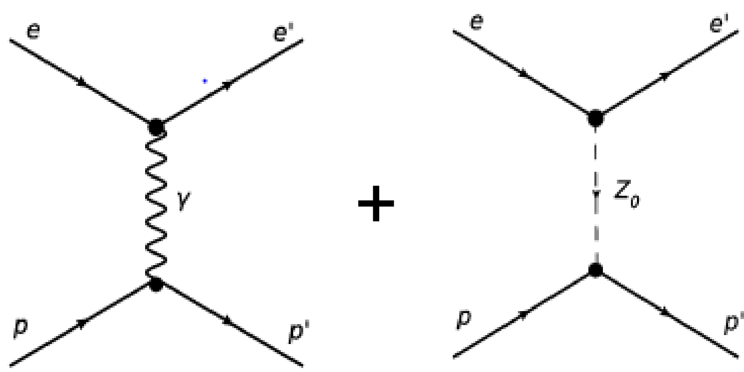
$$r_E^2 \equiv -6\hbar^2 \frac{d}{dQ^2} G_E(Q^2)\Big|_{Q^2=0}$$



Potential reach of ERL-FFAG with an A1 style detector and point-like target (courtesy J. Bernauer).

Needs study!

Proton Weak Charge



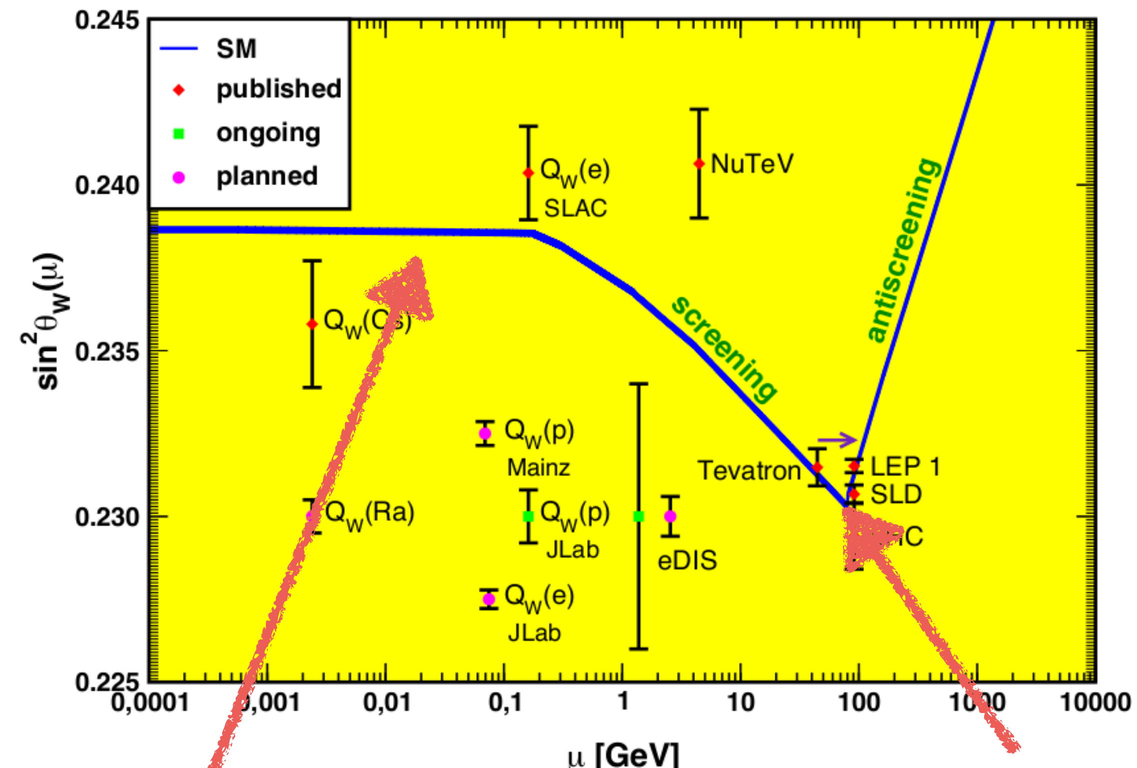
Parity-Violating Asymmetry

$$A_{PV} = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$$ +- = electron helicity

is related to the Weinberg angle

$$A^{PV} = \frac{-G_F Q^2}{4\pi\sqrt{2}\alpha}(Q_W^p - F(Q^2)),$$

$$Q_W^p = 1 - 4 \cdot \sin^2(\theta_W)$$



test SM prediction for running to low energies

precise Z-pole measurements

- Example: if dark sector contains a copy of SM, new P-violation at low energies due to mixing of dark photon with "dark Z"

[Davoudiasl, Lee, Marciano,'12]

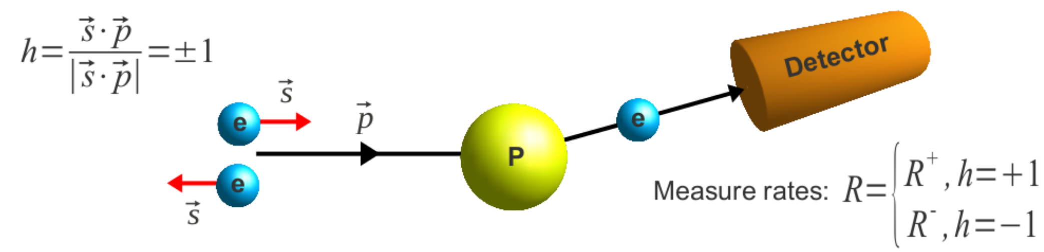
Proton Weak Charge

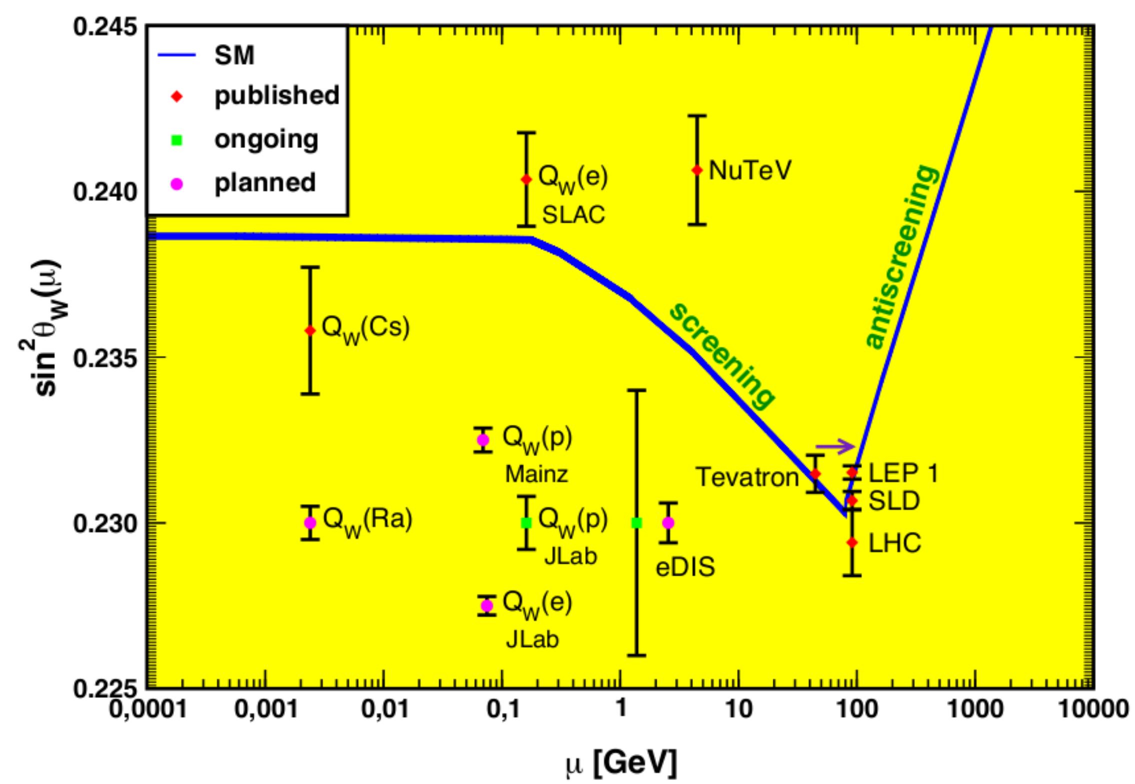
- Ongoing/planned experiments (Qweak/P2) will achieve

$$\frac{\Delta \sin^2 \theta_W}{\sin^2 \theta_W} = 0.3\%/0.15\%$$

- May be advantageous to go to higher energies, ~500 MeV vs. 200 MeV at MESA - could be a good fit for Cornell [R. Carlini]

- Required high internal target density is a challenge for this experiment at FFAG ERL - needs further thought





$$A^{PV} = \frac{-G_F Q^2}{4\pi\sqrt{2}\alpha}(Q_W^p - F(Q^2)),$$

INTENSE ELECTRON BEAMS WORKSHOP

CORNELL UNIVERSITY, JUNE 17-19, 2015

CORNELL LABORATORY FOR ACCELERATOR-BASED SCIENCES AND EDUCATION — CLASSE

Registration will close on May 31, 2015.

With the advent of high power photoinjectors and high performance superconducting RF acceleration, there is the potential for low energy electron beams with currents up to 10 times higher that those generally available today. This workshop will explore the physics opportunities that will be opened up by such beams, focusing on **parity violation**, the search for **dark matter, dark photons and axions**, and **electromagnetic nuclear physics**, as well as the accelerator, detector, target and polarimetry **technologies** that make them possible. Discussion will focus on electron beams with energies up to 500 MeV and electron current of up to 100 mA (unpolarized) and 10 mA (polarized) with energy recovery, with the goal of answering:

1. What is the potential reach of experiments using very intense low energy electron beams?
2. What technical challenges need to be overcome to reach those goals?

Working Groups

- **Parity Violation** -- co-conveners: Kent Paschke (U. Virginia), Maxim Perelstein (Cornell)
- **Dark Matter, Dark Photons, Axions** -- co-conveners: Gordan Krnjaic (Perimeter Inst.), Bogdan Wojtsekhowski (JLAB), Philip Schuster (Perimeter Inst.)
- **Electromagnetic nuclear physics** -- co-conveners: Jan Bernauer (MIT), Ronald Gilman (Rutgers)
- **Technology** -- co-conveners: Vadim Ptitsyn (BNL), Joe Grames (JLAB), Alexander Nass (Fz. Jülich)

Quick Links

WG Reports will focus on opportunities in these areas - ***STAY TUNED!***

http://www.classe.cornell.edu/NewsAndEvents/IEBWorkshop/